PRECISE TRAJECTORIES AND ORBITS OF METEOROIDS FROM THE 1999 LEONID METEOR STORM

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Abstract. Photographic multi-station observations of 47 Leonid meteors are presented that were obtained from two ground locations in Spain during the 1999 meteor storm. We find an unresolved compact cluster of radiants at $\alpha = 153.67 \pm 0.05$ and $\delta = 21.70 \pm 0.05$ for a mean solar longitude of 235.282 (J2000). The position is identical to that of the Nov. 17/18 outburst of 1998, which implies that both are due to comet 55P/Tempel-Tuttle's ejecta from 1899. We also find a halo which contains about 28% of all meteors. The spatial distribution of radiant positions appears to be Lorentzian, with a similar fraction of meteors in the profile wings as the meteor storm activity curve.

Keywords: Comet dust trial, dispersion, Leonids 1999, meteor, meteor orbit, meteor trajectory, orbital dynamics

the orbits of the meteoroids to be more similar. This would be a good test for our error estimates and an invitation to push the capability of the technique to the limit. Observations of the storm were performed from Spain, while similar observations from California served for reference. Only part of the data have been reduced at this time. Here, we report on the first data measured in Spain during the 1999 Leonid meteor storm.

2. Methods

The measurements were made from two observing sites at Punto Alto (38° 22' 45".25 356° 58' 1".88; height 772m) and Casa Nueva (39° 07' 01".30 357° 16' 39".90; height 785m) in Spain. Time exposures were made by fixed cameras, while an all-sky intensified video camera recorded the time of occurrence of the bright meteors. We deployed the same clusters of small (35 mm format) cameras with 50 mm f/1.8 optics and crystal controlled rotating shutters as in Betlem *et al.* (1999). The negatives were developed, scanned on Kodak Photo CD, and analyzed using interactive Astroscan software in the normal manner (Betlem *et al.*, 1997; 1998). The typical astrometric accuracy is 0.003°.

3. Results

Around 1100 meteors were photographed from Punto Alto and about 700 were photographed from Casa Nueva on the night of Nov. 17/18, 1999. The first 65 precisely reduced orbits are presented in this paper.

Of the first 65 precisely reduced orbits, 47 turn out to have convergence angles larger than 20 degrees. These provide the most accurate results and are listed in Tables I and II. The convergence angle is the angle between the two planes defined by each observing site and the meteor trajectory. Table I gives the trajectories of 47 Leonids that are part of the 1999 Leonid meteor storm. The columns list apparent visual magnitude (Mv), beginning and end height (km), heliocentric velocity (Vh), geocentric velocity (Vg), geocentric radiant coordinates (α, δ), and convergence angle (Q). The heights represent the lowest and highest point of the recorded trajectory, respectively, which does not take into account that some meteors may have entered the field of view, while others may have left, without their actual beginning or end point being recorded. Table II lists the corresponding orbital elements of these 47

TABLE II

Code	q	± q	1/a	± 1/a	i	± i	ω	± ω	Ω	± Ω
1999008	0.9843	0.0002	0.092	0.022	162.62	0.07	172.24	0.23	235.21500	0.00000
1999010	0.9844	0.0002	0.105	0.001	162.49	0.07	172.35	0.16	235.23561	0.00000
1999011	0.9843	0.0005	0.098	0.014	162.65	0.11	172.28	0.50	235.23561	0.00000
1999013	0.9842	0.0007	0.125	0.017	162.34	0.30	172.09	0.65	235.24906	0.00000
1999014	0.9843	0.0003	0.043	0.010	162.06	0.13	172.38	0.27	235.25277	0.00000
1999015	0.9844	0.0009	0.076	0.006	162.58	0.38	172.41	0.80	235.25314	0.00000
1999016	0.9837	0.0005	0.064	0.012	162.74	0.18	171.83	0.39	235.25536	0.00000
1999017	0.9845	0.0000	0.082	0.003	162.53	0.01	172.47	0.02	235.25974	0.00000
1999018	0.9847	0.0003	0.137	0.013	162.47	0.15	172.56	0.32	235.25992	0.00000
1999026	0.9850	0.0005	0.105	0.012	162.73	0.23	172.93	0.49	235.26866	0.00000
1999028	0.9845	0.0003	0.078	0.013	162.42	0.11	172.51	0.23	235.27117	0.00000
1999029	0.9842	0.0005	0.103	0.021	162.51	0.22	172.11	0.49	235.27140	0.00000
1999030	0.9841	0.0002	0.071	0.008	162.53	0.11	172.16	0.20	235.27218	0.00000
1999031	0.9863	0.0004	0.123	0.045	161.76	0.24	174.22	0.52	235.27277	0.00000
1999032	0.9846	0.0046	0.078	0.005	162.64	0.02	172.56	0.07	235.27313	0.00000
1999033	0.9843	0.0002	0.092	0.022	162.62	0.07	172.24	0.23	235.21500	0.00000
1999036	0.9846	0.0002	0.107	0.006	162.54	0.06	172.49	0.21	235.27618	0.00000
1999037	0.9839	0.0003	0.134	0.023	162.39	0.12	171.85	0.28	235.27697	0.00000
1999041	0.9839	0.0005	0.092	0.022	162.86	0.21	171.95	0.45	235.27856	0.00000
1999043	0.9848	0.0000	0.115	0.117	162.51	0.01	172.69	0.04	235.28078	0.00000
1999044	0.9845	0.0001	0.102	0.005	162.51	0.05	172.40	0.11	235.28111	0.00000
1999045	0.9829	0.0005	0.093	0.011	162.50	0.20	171.08	0.43	235.28119	0.00000
1999046	0.9852	0.0007	0.100	0.026	162.97	0.36	173.16	0.77	235.28150	0.00000
1999047	0.9874	0.0002	0.105	0.007	162.93	0.19	175.93	0.40	235.28214	0.00000
1999050	0.9844	0.0000	0.082	0.010	162.49	0.02	172.34	0.06	235.28427	0.00000
1999057	0.9845	0.0002	0.077	0.030	162.65	0.07	172.52	0.18	235.28756	0.00000
1999058	0.9846	0.0000	0.078	0.011	162.38	0.02	172.56	0.06	235.28807	0.00000
1999059	0.9845	0.0002	0.100	0.010	162.56	0.06	172.40	0.14	235.29373	0.00000
1999061	0.9850	0.0003	0.086	0.013	162.66	0.13	172.91	0.27	235.28957	0.00000
1999064	0.9817	0.0000	0.095	0.004	162.08	0.01	170.16	0.04	235.29085	0.00000
1999065	0.9843	0.0003	0.097	0.018	162.58	0.13	172.27	0.29	235.58202	0.00000
1999066	0.9857	0.0003	0.165	0.017	162.20	0.10	173.53	0.37	235.29116	0.00000
1999067	0.9838	0.0004	0.122	0.008	162.25	0.17	171.78	0.37	235.29149	0.00000
1999071	0.9833	0.0003	0.151	0.016	162.31	0.09	171.22	0.29	235.29283	0.00000
1999074	0.9844	0.0002	0.124	0.014	162.46	0.08	172.27	0.17	235.29479	0.00000
1999079	0.9833	0.0007	0.119	0.011	162.47	0.27	171.36	0.58	235.29797	0.00000
1999081	0.9848	0.0008	0.089	0.015	162.61	0.35	172.74	0.74	235.29842	0.00000
1999085	0.9842	0.0001	0.106	0.009	162.47	0.02	172.15	0.07	235.30104	0.00000
1999087	0.9844	0.0003	0.072	0.025	162.42	0.15	172.41	0.32	235.29975	0.00000
1999088	0.9843	0.0001	0.079	0.002	162.65	0.03	172.26	0.06	235.30348	0.00000
1999105	0.9857	0.0015	0.062	0.023	162.37	0.79	173.75	1.65	235.31298	0.00001
1999106	0.9843	0.0001	0.116	0.006	162.52	0.04	172.22	0.13	235.31273	0.00000
1999112	0.9828	0.0005	0.084	0.029	162.26	0.13	171.06	0.41	235.30944	0.00000
1999114	0.9838	0.0008	0.122	0.012	162.37	0.16	171.80	0.69	235.32150	0.00000
1999115	0.9843	0.0003	0.129	0.007	162.65	0.13	172.14	0.27	235.32358	0.00000
1999117	0.9851	0.0001	0.083	0.006	162.67	0.03	173.10	0.11	235.32502	0.00000
1999129	0.9844	0.0002	0.095	0.004	162.59	0.06	172.36	0.17	235.34490	0.00000
Mean	0.9844	0.0004	0.099	0.016	162.50	0.14	172.39	0.33		
Stand. Dev.	0.0009		0.024		0.22		0.86			

-0.36 degrees per degree solar longitude. In this system, the 1999 Leonid storm radiant was at α = 153.39 ± 0.05 and δ = 21.80 ± 0.05 (J2000). Compare this to the radiant position of the 1998 outburst on Nov. 17/18, at α = 153.43 ± 0.09 and δ= 21.97±0.14 (Betlem *et al.*, 1999). We conclude that both are identical, which implies that the second outburst in 1998 was in fact caused by the same dust trailet responsible for the 1999 Leonid storm. Based on the models by McNaught and Asher (1999), both must be due to ejecta from 1899.

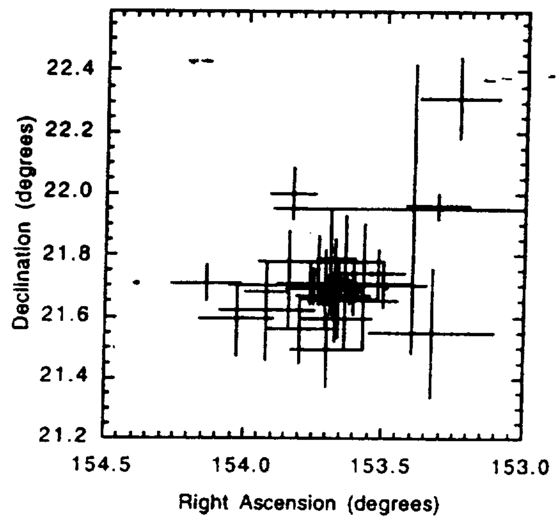

Figure 2. Geocentric radiant position of Leonids at the time of the 1999 Leonid storm.

With at least 13 out of 47 meteors (28 %) part of this halo, it is unlikely that the halo is due to the relatively weak annual Leonid shower or the (almost) absent Leonid Filament (Jenniskens and Betlem, 2000). The halo implies strong wings in the radiant dispersion of the storm, unlike a Gaussian distribution. Instead, the spatial radiant distribution appears similar to the Lorentzian shape of the nodal distribution (Jenniskens *et al.*, 2000). Indeed, the relative flux in the background profile versus the total flux curve of that Lorentzian curve is 28%, which is in agreement with the distribution of radiant positions.

The distribution of orbital elements may serve to improve meteor stream models. It is very significant that all observed orbits are well dated, being ejected during the return of comet 55P/Tempel-Tuttle in